Recent Advances In The User Evaluation Methods And Studies Of Non-Photorealistic Visualisation And Rendering Techniques

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Abstract

While traditional computer graphics research to this day still focuses on the production and assessment of photorealism, a relatively new field, the one of non-photorealistic rendering (NPR), has produced results that focus on viewer engagement by the use of stylization, abstraction and expressiveness. In this paper we briefly describe some of the techniques used today and then proceed to identify some the most important evaluation studies associated with NPR by categorizing them and outlining the applications they have been used in, their methods and finally the results and their impact on future work in this area.

Keywords--- **Computer graphics, Non-photorealistic rendering, User studies, Experiment design, Human-computer interaction.**

1. Introduction

Non-photorealistic rendering techniques can today be broadly considered as derivatives of four different methods: a) stylized lighting b) pen and ink c) volume illustration and finally d) edges and silhouettes. Comprehensive surveys of these techniques have been conducted by Strothotte et al. [25], Gooch et al. [26] and Sayeed et al. [27].

Stylised lighting is usually facilitated either by tone shading or cartoon rendering. The standard method for tone shading was introduced by Gooch et al. [1] and consists of a lighting model simulating the cool-to-warm shades found in technical illustration. On the other hand, cartoon rendering can be defined as a distinctive style, primarily characterised by large uniformly or widely-banded coloured surfaces with detail restricted mostly to outlines. A representative example is the work by Lake et al. [2].

The method of pen and ink NPR is based on the traditional human illustration method and is easily, out of the aforementioned four, the method mostly associated with artistic hand-driven work. Pen and ink NPR is based on strokes with further engagement and added detail introduced by hatching, a group of strokes with spatial coherent direction and quality, usually in the form of diagonal lines. Hatching can express shadow, depth and even lighting. Representative work in pen and ink NPR tends to focus either on direction fields as shown by Girshick et al. [7] or textures as shown by Praun et al. [8].

The combination of NPR with volume rendering has been a recent, if predictable, development since the first can clearly offer reduced parameterisation requirements to the latter's inherent ability to visualise complex medical or weather information. Two methods of NPR volume rendering can generally be recognised. The first is via feature enhancement through traditional volume rendering models which was first introduced by Ebert et al. [9]. However, by avoiding traditional volume rendering approaches, alternate NPR methods can be produced such as the one described by Lue et al. [10], methods capable of producing results closer to the ones produced by a human hand while still using volume sets.

Edges and silhouettes (with silhouette defined as the outline of an object and coming in five different types, silhouette edges, ridge edges, valley edges, border edges and shadow or texture boundary outlines) NPR techniques have the most sub-classifications when compared to the other three. They can generally be categorized as image-space and object-space methods. Image-space methods utilize discontinuities in the image buffers and extract silhouette edges using image processing methods. They are thus a simple yet effective way to generate the silhouettes of a 3D scene with some representative work in the area conducted by Mitchell et al. [3] and Nienhaus et al. [4]. Object-

space silhouette algorithms on the other hand differ from the image-based ones by relying on geometry description and information. Work in the area includes the one conducted by Buchanan et al. [5], who presented a method based on a technique called the edge buffer while Benichou et al. [6] mapped the hierarchical Gaussian sphere (used to extract silhouette edges) and its arcs to a cube surrounding it in order to accelerate their algorithm. There have also recently been hybrid techniques combining both approaches such as the one demonstrated by Kalnins et al. [6] that introduce brush path parameterisation to represent a silhouette, combined with an image-space local search to track silhouettes between frames providing frame coherence.

2. Evaluation Studies And Methods Of NPR Techniques

For obvious reasons, such as most notably the short life span of the field so far plus also the artistic individuality associated with it, only a few number of publications to this day have focused on evaluation studies of non-photorealistic approaches, models, still images and applications and their overall impact.

While this situation is certainly improving and more researchers begin to realise the potential and tackle the subject by conducting user studies on this, at the moment the evaluation experiments addressing it can be broadly categorized in the following seven types.

2.1. Psychological Applications

Psychology and computer graphics rendering have been two fields where a lot of work has been conducted, including a large number of evaluation study experiments. Unfortunately, most of these studies have largely concentrated on photorealism or photorealistic virtual reality rather than the investigation or assessment of issues related to stylized NPR depictions of either still images or 3D objects and environments. Despite this fact, the possibilities expressive rendering has to offer because of its flexibility and also association with traditional artwork in various psychology paradigms is recognized and notable research in the area has been emerging.

For example, Duke et al. [11] summarized and investigated the affective qualities of images in a series of experiments that addressed the emotive qualities of images and their effect on human subjects. The authors, via their evaluation experiments, explain how the interpretation of the results they acquired requires a high-level model of cognitive information processing and then proceed to use such a model in order to examine and analyze more recent empirical results on judgment and rendering.

Another very interesting study in the subject [12] conducted an experiment where conclusions where drawn from the cognitive processes of NPR via the use of eye-tracking. The method of eye-tracking was chosen to determine where viewers look in regular photographs and then NPR images. 74 viewers examined the same number of locations in photos and in expressively rendered images with uniformly high or low detail (in five different conditions).

Results show that the subjects were attracted to areas where detail is locally preserved in meaningfully abstracted images. These results agree with the concept that traditional art chooses to carefully manipulate drawn detail to captivate the prospective audience.

Moreover, it also seems to validate the method of the usage of meaningful and not vague abstraction used in DeCarlo et al. [13], another piece of research work by some of the same authors, describing the importance of suggestive contours in non-photorealistic, computer-driven illustration. It should also be noted that results also suggest eye-tracking, despite its unorthodox nature, can be a useful tool for further evaluation in the non-photorealistic field.

In a similar vein, Halper et al. [14], [15] are advocates of the necessity of the development of a psychological theory within non-photorealistic rendering since they argue that despite the inherent flexibility of the rendering style in question, the psychological functionality of NPR remains largely unexplored. They support that argument by considering aspects of NPR in terms of general, biological, social and environmental psychology paradigms plus also by using results from a number of recent evaluation studies.

One of these studies (on figure ground segregation and NPR-guided selection) involved subjects clicking on three objects from a set of twenty. Close to 50% of the objects used in the experiment were toon-rendered with the other half rendered with the water-colour style used for the background. One of two test conditions to control for biasing based on object preference were assigned to all human subjects.

In the end, the participants were geared towards selecting at least two or more of the cartoon-style objects. This suggests the very interesting result that the shading was a greater factor in selection choice than the object and its features.

2.2. Architectural Applications

One of the first, if not the first non-photorealistic rendering evaluation was conducted by Schumann [16]. In this study, the usability of computer-generated

images was measured particularly regarding the potential communicative goals during design concept development with professionals of the area (architects, a large number of them using existing CAD systems) serving as participants.

The 54 architects used as human subjects for this study were shown three different images depicting the same building plan. First, a CAD plot image, then a constant shading image and finally an expressively rendered image generated by a sketch-renderer developed by some of the co-authors of the work [17].

After being shown the three images, subjects were asked to answer various questions. First, they were asked to say which image or images they would want to use to show a first draft to a client plus which image they would ideally use for a final presentation of an idea. The subjects were also asked to provide a verbal explanation of the choice above. Furthermore, subjects were asked about a number of possible effects of the images, to be rated on a scale of 5 (strongly disagree) to 1 (strongly agree). Participants were also asked to give an additional verbal judgement about the images and also specifically state how they would make changes to the design being visualized. For this they were given four clear options to choose from, a verbal description, by gesturing or by pointing relative to the image, by drawing on another new sheet of paper, or by drawing directly onto the image / images given.

The results show that the different kinds of renditions actually have a very different effect on viewers. Moreover, from the three image types, the stylized images appear much more appealing for interaction compared to the other two (as indicated by the last, third, task of the experiment). This indicates that non-photorealistic images actually do deserve their place in the repertoire of all CAD systems.

2.3. Medical Applications

Surgery planning and training is yet another area where non-photorealistic rendering techniques can be applied, proved by the work shown by Tietjen et al. [18], which again was the sole pioneering publication in this area.

Firstly, a scene graph-based combination of silhouette, surface, and volume rendering is described. This is further facilitated by stroke extraction and stroke rendering being decoupled from each other to allow for the display of correctly determined visible lines with stylization applied. The authors go on to test the potential of this combination of silhouette rendering with the traditional rendering styles for medical visualization by collecting feedback from 33 medical professionals and laypersons.

Results indicate that silhouettes are an appropriate extension of the existing visualization possibilities. In a direct comparison between the transparent surface and the hybrid visualization, the silhouettes are regarded as superior. While the exclusive application of silhouettes without any further information about shape or colour of the objects was regarded by the participants in an unfavourable manner, with additional information such as coloured silhouettes or highly transparent surfaces, the silhouettes were rated to be very good.

Overall, from the experiment it emerges that stylised silhouettes are appropriate to convey spatial information based on clinical data.

2.4. Perception Of Space

The first publication presenting an approach towards quantitatively evaluating spatial perception in a functional, non-photorealistic, stereo, immersive environment [19] borrows from both the art and perceptual psychology communities with the aim of providing a methodology for conducting user studies to perceptually validate new rendering approaches within immersive environments.

Experiments involved a number of direct walking tasks of approaching a mark both in a physical hallway and also in a non-photorealistic approximation of that in a 3D model of the same hallway, visualized through an HMD (head-mounted display). The mark was placed on the ground at distances of 2m, 3.5m, and 5m from the 12 participating subjects.

From the results the authors have found that there is a significant statistical difference in performance between the real world condition and the immersive virtual environment condition. The results of the perceived versus intended distance analysis of their direct walking task experiments are approximately 66.0% of the intended distance in the feature edge (NPR) immersive environment and about 97.0% in the real world. These results are expected, particularly given the previous body of work in perception. While 66% does seem to be a low number, in context it does correspond well with previous findings in traditionally (and not NPR) rendered immersive environments in which perceived distances were found to be 50% to 75% of the intended distances.

2.5. Texture-Based Depiction

A pilot study by Jackson et al. [20] examines how expert graphic design knowledge can provide a fast and robust visualization evaluation methodology, that is one that could potentially assess scientific visualizations for their scientific value whilst also

attempting the improvement of the composition and the design of the visualizations.

Graphic designers are trained to judge how well visual designs convey specific pieces of information so the authors of this particular publication believed they can evaluate scientific visualizations for how well they fulfill design goals based both on the scientific task represented and the actual visual design and put that claim to the test.

One designer gave grades to the visualization methods as an estimate of user performance for an advection task on two data sets with each method. To begin with, he ran through a previous study as training in order to understand the advection task and was then presented with two sets of images.

Results from the pilot study demonstrate that the subjective results of the designer's critique corresponded well to previously measured numeric values for performance.

Two comprehensive experiments that assess the effectiveness of texture patterns in conveying 3D shape information have been conducted by Kim et al [21]. The investigation was focused on how particular texture components influenced shape perception so participants were asked to identify intrinsic shape features and surface orientation using different viewing conditions.

Results in general confirmed the hypothesis that accurate shape perception is facilitated to a statistically significantly greater extent by some principal direction texture patterns than by others. Specifically, it was showed that a) assuming conditions of perspective projection are met for both viewpoint conditions, the correct identification of shape type and surface orientation of the stimuli was achieved best when the visualization of the textured quadric patch was with a pattern displaying indications of the first and second main directions and b) shape classification judgments of the surface do largely rely on whether critical shape indicators are resembling the features of a form, a fact that seems to be interpreted in a preferential way by the participant subjects and consistently with what would be the case if these aforementioned indicators followed a line of curvature on a convex form.

Acevedo et al. [22] have more recently evaluated 2D visualization methods and how effective they were by drawing subjects from the pool university design educators, namely the Illustration Department at the Rhode Island School of Design (RISD). The authors first defined a space of visualization methods using basic visual elements including icon hue, icon size, icon density, and background saturation and then conducted their pilot study by presenting the subjects with single variable visualization methods. Results verify the effectiveness of individual visual elements according to the design factors set by the authors.

An approach that is also very similar to the one followed by Isenberg et al. [23] (and more recently extended to a more technical study by a group of the same authors in [28]), consisting of an observational study with three groups of users to examine their understanding and assessment of hand-drawn pen-and-ink illustrations of varying objects in comparison with NPR renditions of the same 3D objects.

For this observational study, the authors decided to focus on eight illustration end users (general university population, 5 male, 3 female), eight professional illustrators (either advanced art students or professional artists and illustrators, both with a background in drawing; 3 male, 5 female), and eight NPR researchers (graduate computer graphics students with an NPR background, 7 male, 1 female), with 24 participants in total. Use of three methods were made during the study, a pile-sorting task, a semi-structured interview task and a questionnaire task.

Overall results show that people perceive differences between those aforementioned two different types of illustration but that those that look computer-generated are still highly valued as scientific illustrations.

For example, during the semi-structured interview task, from the comments made by participants it emerges that computer-generated images are recognized because of their cleaner and tighter appearance as compared to the hand-drawings ones, since they are too perfect (by employing round dots and long lines), too sterile and do vary in their lines or stipples. These images are also often characterized by the subjects as having too much detail and complexity resulting in a tedious illustration and thus impossible production process for a human artist's hand.

Finally, computer-generated images look three-dimensional, closer to appeasing as 3D objects and use a lot of shading and lighting. As for hand-drawn images, some of the characteristics identified according to the participants included line variability, organic feeling, weighted lines, not too much detail and looseness. Mark direction, variability in the mark or mark placement were features named most often, by 20 out of the 24 participants.

2.6. Learning Applications

Gooch et al. [24] present a method for creating black-and-white illustrations from photographs of human faces. In addition to that an interactive technique is demonstrated for deforming these black-and-white facial illustrations to create caricatures which highlight and exaggerate representative facial features. The authors then proceed to evaluate the effectiveness of the resulting images through

psychophysical studies to assess accuracy and speed in both recognition and learning tasks.

Participants at the experiments were presented with sequences of images of familiar faces. Each participant was asked to say the name of the person pictured as soon as that person's face was recognized. For this, reaction times but also accuracy of the answers were recorded. All images were presented to the participants in three separate conditions or combinations, a) using either photographs and facial illustrations, b) photographs and caricatures, or finally c) facial illustrations and caricatures.

The results from these studies show that the facial illustrations and caricatures generated using the techniques mentioned in the publication are as effective as photographs in recognition tasks with human subjects. For the learning task the NPR illustrations generated are learned two times faster than photographs and NPR caricatures are learned one and a half times faster than photographs.

It is finally suggested from the results that NPR facial illustrations and caricatures, particularly the ones generated using the authors' techniques, are useful in a number of potential applications which can range from entertainment and education to low-bandwidth telecommunications and psychology research.

2.7. Natural Phenomenon Applications

Healey et al. [29] conducted a user study in order to explore the capabilities of their NPR techniques (which employs approaches from master paintings and human perception to visualize multidimensional datasets), by running a validation experiment with 15 subjects and a set traditional weather displays versus NPR-enhanced weather maps (both showcasing temperature, precipitation, wind speed and wind direction).

The aim was to test the ability of their visualization approach to support common analysis tasks on real-world data, compare them with a more traditional display method and finally study whether the common method of the combination of images that work on their own can also offer an engaging multidimensional visualization.

Results showcased that the subjects preferred the NPR approach of representing temperature and wind speed while the standard visualization method was favoured for precipitation. Also, the human subjects were surprisingly better at identifying high temperature, rapid temperature change and the combination of high precipitation and high wind speed in the NPR visualization rather than the traditional one.

3. Conclusion

In this paper we have attempted to first briefly summarize the main NPR rendering techniques today and then proceeded to list a wide range of experiments and studies conducted utilizing them. We have categorized these experiments in seven different distinct types according to the application they targeted and reported on their aim, objectives, methodology and finally individual results.

It is expected to see NPR techniques and methods embraced even more in the future, especially considering the incessant technological advances in modern graphics hardware technology and also real-time algorithms and this will of course have an immediate effect and impact on user studies focused in the same field. For example, particularly exciting fields which are yet to be explored but because of the ever-increasing computational power we should anticipate user studies to emerge soon, are that of NPR in augmented reality and also mobile computing.

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